THE MEASUREMENT AND ANALYSIS OF STRAINMETER DATA FROM ADAMS ISLAND, NOVEMBER 1982 TO JUNE 1983

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The Centre for Cold Ocean Resources Engineering (C-CORE) was established at Memorial University of Newfoundland in St. John's in 1975. Its initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. Ongoing funding now comes from government and industry.

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I. GENERAL

1.1 Introduction

Finite and incremental strain data have been collected and analysed from two C-CORE strainmeter rosettes located 200 metres southwest of Adams Island on Navy Board Inlet. These strainmeters were frozen to a sheet of unfractured and nearly snow free first year sea ice consisting of a 2 cm thick polycrystalline unit underlain by a 1 metre thick anisotropic columnar zone. Grains in the columnar unit were elongate perpendicular to shore and oriented so that their C-axes lay parallel to the shore.

Selected data were also analysed from 46 large scale EDM strain arrays dispersed about the island, as well as from a smaller EDM array placed around the C-CORE strainmeter rosettes.

The C-CORE strain rosettes consisted of three linear variable displacement transducers (LVDTs - Sangamo Model DF2.5) oriented 120° to one another. These were coupled to the ice by four 15 cm long rectangular posts. The transducers, named a, b, and c respectively, were oriented such that leg c lay perpendicular to the shore (Figure 1). The active gage length of the two rosettes were 15 cm (Rosette I) and 14 cm (Rosette II) respectively. Apart from this, both rosettes were of identical construction.

The EDM array surrounding rosette I and II consisted of three laser reflectors mounted at the verticies of a 35 metre equilateral triangle. These targets were named SM1, SM2 and SM3 respectively, and were oriented such that side SM1-3 lay parallel

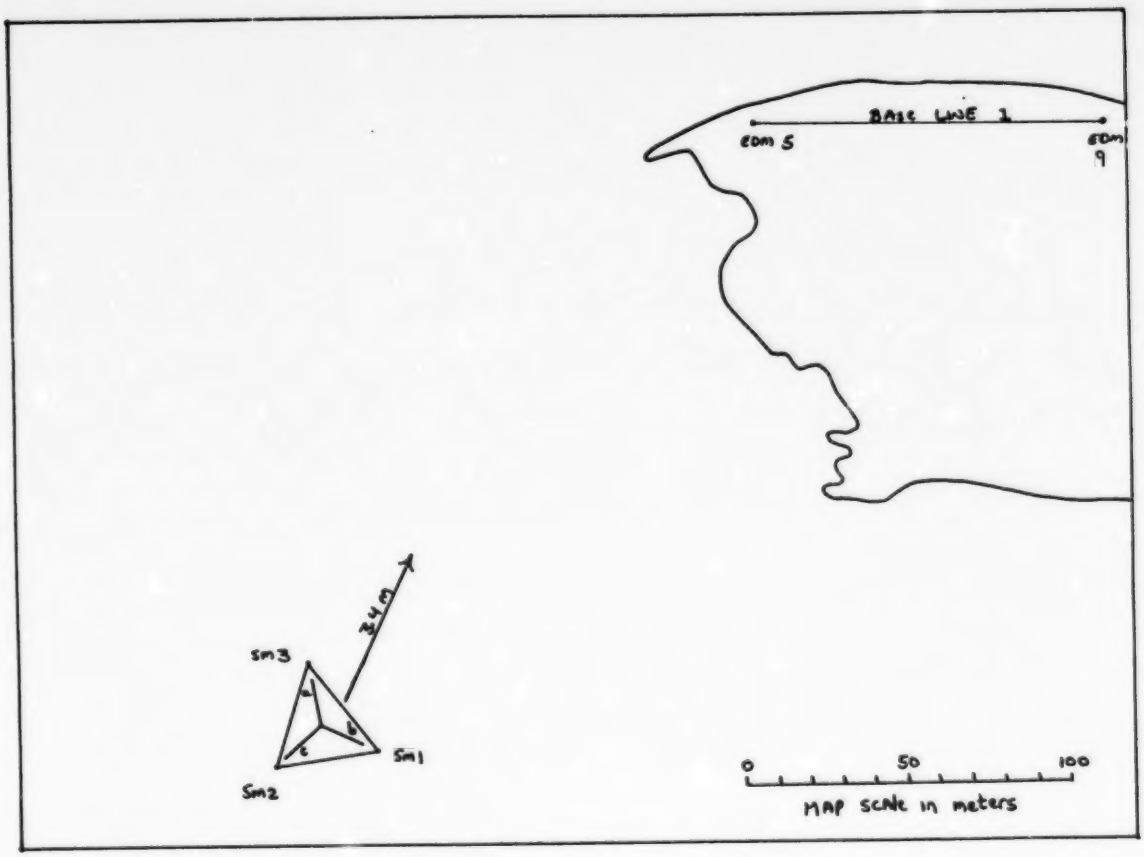

Figure 1: Location of the two C-CORE strainmeter arrays and EDM targets at Adams Island. The arrow gives the average ice displacement during the period 3/20 - 4/27, 1983.

to the shore of Adams Island (Figure 1). Measurements were made intermittantly of each targets' location during the period March 20 - June 10, 1983 with the aid of a Wild T2 theodolite coupled to a Wild DI20 Distomat EDM. These measurements included the azimuthal position of the target with respect to a base line (i.e. the line connecting site EDM 5 with EDM 9 Figure 1), the inclination of the target with respect to the horizon, and the mean distance of the target from EDM site 5 or 8. Mean distances and standard errors about the mean were calculated from ten consecutive measurements in each case. Simultaneous measurements

of barometric pressure and temperature were also made to facilitate the correction of EDM data for atmospheric effects. These values are available through the Division of Building Research at N.R.C.

Apart from this EDM array, strain values were also calculated for 46 EDM strain triangles located about Adams Island during the period March 20 - April 27, 1983. These data made it possible to relate rosette values to the regional strain field surrounding the island (Fig. 2).

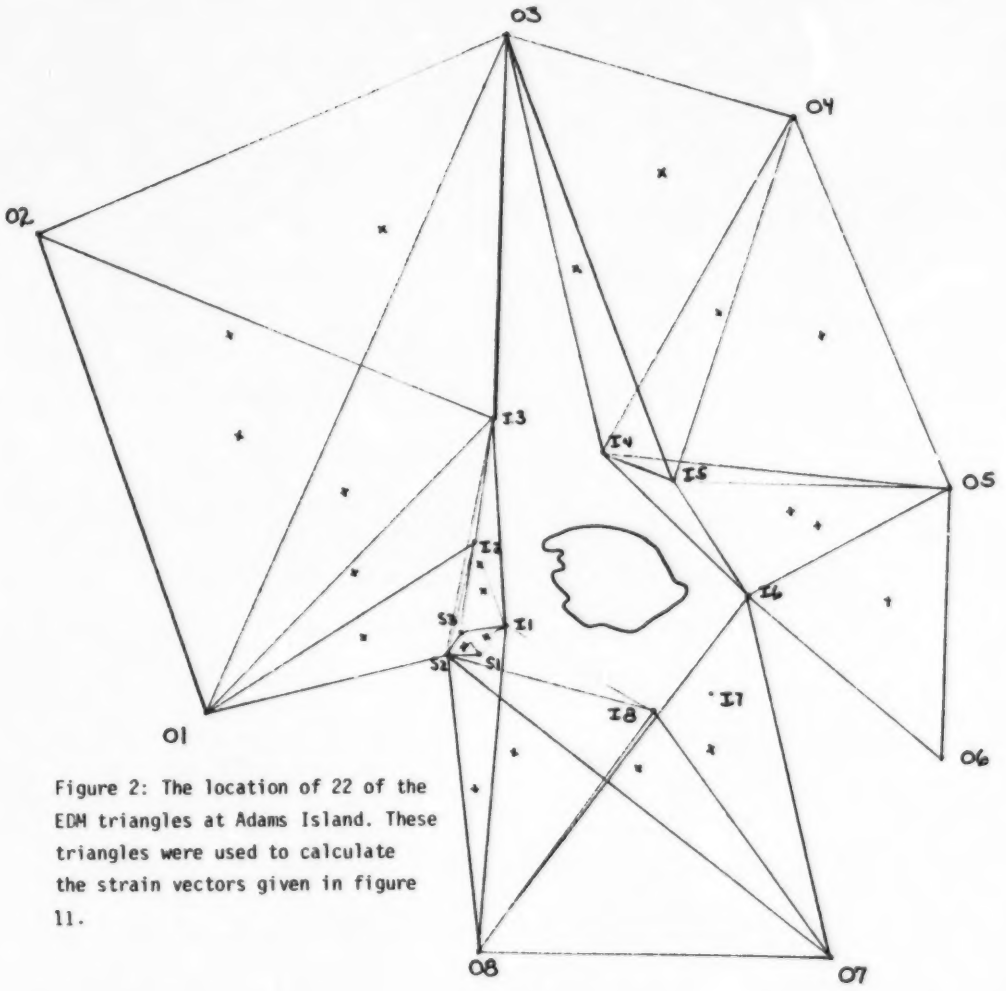

Figure 2: The location of 22 of the EDM triangles at Adams Island. These triangles were used to calculate the strain vectors given in figure 11.

1.2 Strain Gage Installation and Data Collection

1.2.a The C-CORE Strain Rosettes

Installation of the two strainmeter rosettes required the drilling of four 2.5 cm diameter auger holes for each strainmeter; i.e., one centre hole and three leg holes 120° apart. Once drilled, these holes were loosely filled with snow and the strainmeters were lowered into place. Water was then poured into the holes and the strainmeters frozen in. This procedure probably affected the strain measurements themselves since approximately 10% of the active gage length in each case was composed of relatively hard fresh water snow ice rather than softer, brine rich columnar or frazil ice. As a result, the strain readings discussed below may be slightly low.

The two strainmeter rosettes were enclosed within a tight fitting PVC box containing four holes for the legs and centre pin. This protected the strainmeters from accidental damage and prevented ice from forming around the strainmeter core.

Strainmeter values were taken by a H.P. digital voltmeter during March. and a Fluke D.V.M. during all later occupations. The H.P. voltmeter has an resolution of .005 mv., while the Fluke D.V.M. is accurate to .1 mv. Both units were kept warm in the field by enclosing them in well insulated styrofoam boxes kept beneath the author's parka during transport.

Apart from strain data, the voltmeters were also used to record strainmeter temperatures from a thermilinear thermistor incorporated in the body of rosette II.

1.2.b The EDM Strain Rossettes

Installation of the EDM arrays required the drilling of three 10 cm diameter holes 30 cm into the ice sheet, and forcing 2 x 4 poles into each hole. Snow and water were then filled into the hole to freeze the board in place. The target was mounted to the top of each pole and pointed towards EDM Site 5 or 8.

Placement of the theodolite/EDM combination was more complicated, since both the theodolite and tripod had to be set up on site at the beginning of each working day. Slight errors in the positioning of the theodolite over the bench mark, and in setting the height of the EDM above the ground level probably created errors in target positioning on the order of 1 - 3 cm. Similarly, errors were probably incurred as a result of variations in atmospheric conditions between the EDM and the target. Fortunately, however, these are both systematic errors, since they were kept consistent during the measurement period.

2. DATA REDUCTION

2.1 Strain Rosette Data Correction and Strain Determinations

The calculation of strain from LVDT output requires data on the initial gage length, battery voltage at the time of data accession, the voltage output from the LVDT, and a calibration constant for the LVDT itself.

Table 1 gives the calibration constant and gage length for each leg of the two strainmeters.

Strain is defined as $\Delta L/L_O$, where, L_O is the initial gage length of the strainmeter leg, and ΔL is the change in length of that leg between readings. ΔL is directly measured by the LVDT.

As the central core of the LVDT is moved into or out of the LVDT Body, the output of the transducer changes according to the formula:

$$\text{LVDT Output} = \frac{\text{Calibration Constant} \times \text{Displacement in mm}}{\text{Voltage input}}$$

- or more usefully -

$$\text{Displacement in mm} = \frac{\text{LVDT Output} \times \text{Voltage input}}{\text{Calibration Constant}}$$

By recording the LVDT output and battery voltage at the time of data collection, we can define ΔL in mm. This value divided by the original gage length gives the strain measured by each leg

of the rosettes (Table 2).

Corrections for thermal expansion of the strainmeters have been applied to the present data set. The average expansion value for both strainmeters was determined in the lab to be approximately 7.5 microstrains/degree Celsius. This constant was added to the strain values if the temperature increased between strain increments, and was subtracted if the temperature decreased between increments.

2.2 Determination of Finite and Incremental Strain

Incremental strain is defined as the magnitude and orientation of strain developed between any two consecutive gage readings. Finite strain is defined as the total strain suffered by the ice sheet between the initial reading and any subsequent reading.

As mentioned above. any three legs of a strainmeter rosette can be used to define the strain ellipse. From this, E_{max}, E_{min} and Øp can be determined by the formulae

$$\epsilon_{max} = \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3} + \sqrt{\left(\epsilon_1 - \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3}\right)^2 + \left(\frac{\epsilon_2 - \epsilon_3}{\sqrt{3}}\right)^2}$$

$$\epsilon_{min} = \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3} - \sqrt{\left(\epsilon_1 - \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3}\right)^2 + \left(\frac{\epsilon_2 - \epsilon_3}{\sqrt{3}}\right)^2}$$

$$\varphi_p = \frac{1}{2}\tan^{-1}\frac{\frac{1}{\sqrt{3}}(\epsilon_2 - \epsilon_3)}{\epsilon_1 - \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3}}$$

where E_1, E_2, and E_3 are the three measured strains, and Øp is the angle lying between the axis of maximum extension (E_{max}) and E_1.

E_1 in this case was defined as SM1-2 in the EDM array, and as leg C in the two small strain rosettes (Figure 1).

E_2 was defined as the leg lying $+60^o$ from E_1 measured in a counterclockwise direction. This would be SM2-3 in the EDM array and leg a in strain rosette I and II.

Finally, E_3 was defined as the leg oriented 120^o counterclockwise from E_1, i.e., SM1-3 in the EDM Array and leg b in the strainmeter rosettes.

Derivations for the above formulae are detailed in The Strain Gage Primer (Perry, C.C. and H.R. Lissner, (1962) McGraw Hill, New York). Calculated values for incremental and finite strain are given in Tables 3-5.

2.3 Deviatoric Strain, Dilational Strain, and Percent Change in Rosette Area

Given that total strain is small, it is possible to resolve any strain into its deviatoric and dilational components. These two terms are defined as follows: if a circle of unit radius is deformed, dilational strain is the change in area of the circle, and deviatoric strain is the change in shape of the circle produced by the deformation.

Since the initial area of the circle is $\pi r^2 = \pi$, and the area of the resultant ellipse is πab, then

$$\pi(1 + Ed)^2 = \pi(1 + Ex)(1 + Ey)$$

where Ed = the dilation of the circle during deformation, and Ex, Ey are the deviatoric strains applied along the two principal axes of deformation. Neglecting second and higher order terms:

$$Ed = (1/2)\ (Ex + Ey)$$

$$Exdev = (1/2)\ (Ex - Ey)$$

$$Eydev = (-1/2)\ (Ex - Ey)$$

where Exdev and Eydev are determined by subtracting Ed from Ex and Ey respectively.

To determine the change in rosette area during deformation, we can use the following formula:

$$\text{Area A} = \frac{(1 + Ed)^2 -}{} = 2\ Ed$$

These values are given in Tables 3-5.

2.4 EDM Data Collection

Prior to analysis of the Distomat data, all results were corrected for atmospheric effects and changes in sea level/Tripod height. The atmospheric correction formula given in the Distomat manual is:

$$\text{True Distance} = D_o + D_o \times \frac{((282.2 - BP \times .2908) \times 1 \times 10^{-6})}{1 + T \times .00366}$$

where T = temperature in ^oC, BP = barometric pressure in MB, and D_o = EDM Distance.

Once corrected for atmospheric variations, the EDM

measurements were then corrected for variations in sea level and/or tripod height. This was accomplished in two stages. First, the absolute height between theodolite and EDM target was calculated. Following this, the horizontal distance between theodolite and target was determined.

Theodolite/Target height was calculated from the formula

$$\text{Height} = d \times \sin \emptyset$$

where d is the atmospheric corrected EDM distance, and $\emptyset$ is the compliment of the vertical angle measured from the theodolite to the target. Since minor variations in the computed height values were noted in this analysis, it was decided to use the average height value obtained from each set of measurements in the following calculations.

Once an average height value was determined, the horizontal distance between theodolite and target was calculated by Pythagorian theorem; i.e. Distance $= \sqrt{\text{EDM Dist}^2 - \text{ht}^2}$.

2.5 The Determination of Strain Values from the EDM Data

The magnitude and orientation of strain within each leg of the EDM triangle is a simple trigonometric problem involving two right triangles. The geometry of this situation is given in Figure 3. In this diagram, point S is the benchmark location of the theodolite, and F and I are two vertices of the strain triangle. The information given includes the measured distances between the theodolite and the target (D_I and D_f respectively), and the angular relationship between the baseline (line SN) and target (A_I and A_f). From this we can determine:

$$X_I = \text{Cos } A_I \times D_I$$

$$X_f = \text{Cos } A_f \times D_f$$

$$\text{and } X = X_I - X_f$$

Similarly, we can define y as being equal to Sin A_I x D_I - Sin A_f x D_f. Displacement magnitude FI can then be defined by pythagorium theorem as the square root of Y^2 and X^2 and the angle of movement with respect to the baseline can be defined as the arc cosine of X/X_I. If Y is negative, then this angle should be negative as well.

All length values were converted to strain values in order to allow direct comparison with those acquired from the two C-CORE strain rosettes. In calculating strain, L_o was defined as the length of each side of the triangle on March 20, 1983 at 11:30 a.m., and L_{final} was measured on April 27, 1983 at 2:45 p.m.

Formulae used to calculate the principal axes of strain from the EDM data are given above and on pages 119 - 123 of the Strain Gage Primer (Perry and Lissner, 1962). Strain values are given in Table 6.

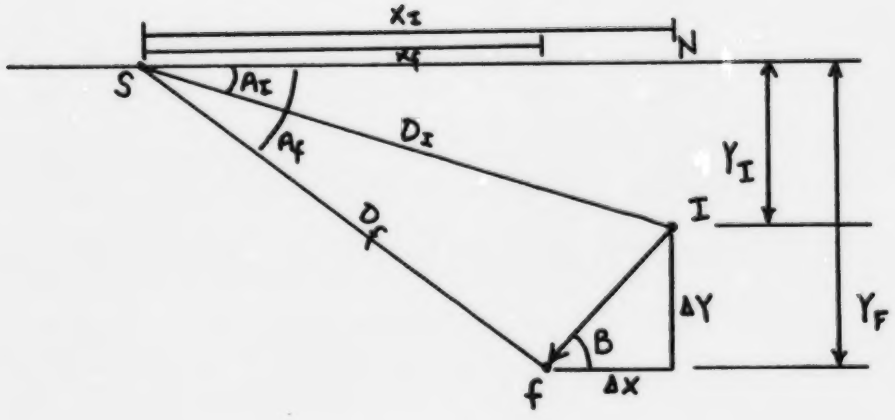

Figure 3: Geometry for determining the displacement of EDM targets. See report for discussion.

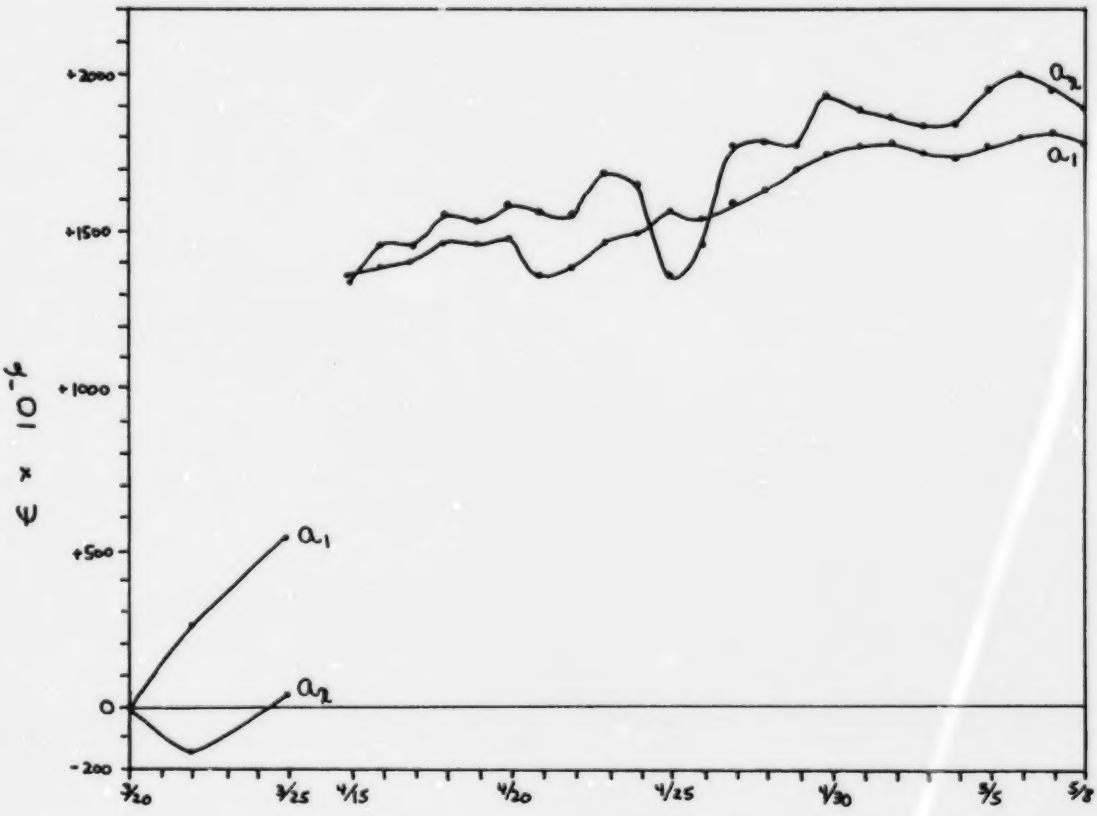

Figure 4 Finite strain in the two C-CORE strain rosettes. These diagrams compare the strains measured by each leg of the two strainmeters.

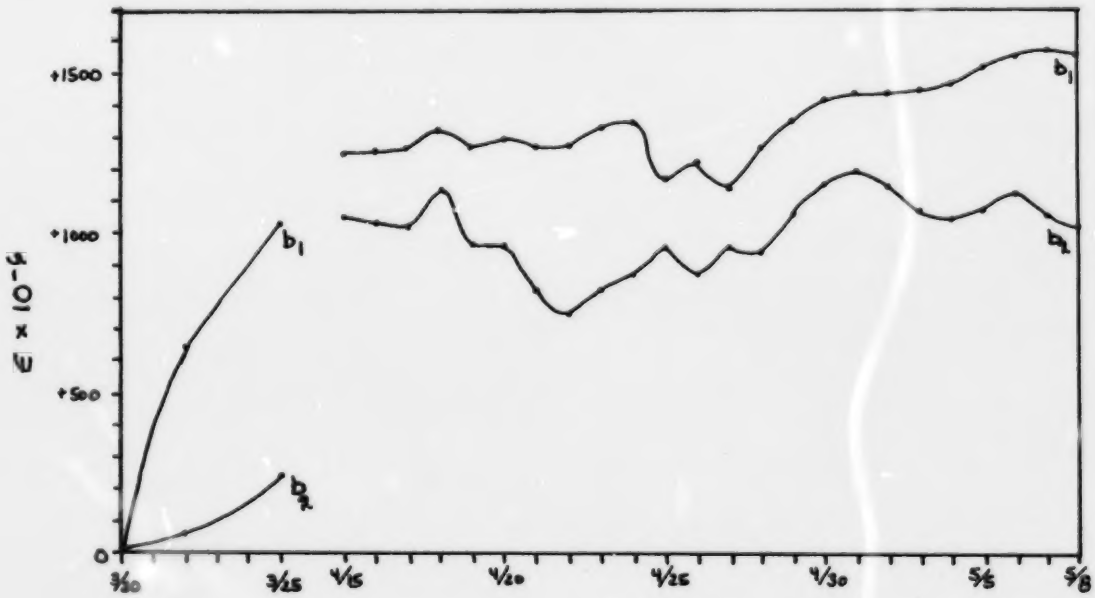

Figure 4 continued...

3. DATA ANALYSIS

3.1 Corrected Strainmeter Values

Temperature corrected strain values for each of the six strainmeter legs are given in Table 2 and are graphically compared in Figure 4. These figures show that strain values measured between similarly oriented strainmeter legs were divergent during the March occupation, but followed very similar trends during April and May. This suggests that "freezing in" was probably occuring throughout the March occupation, and that equilibration had taken place by April 15. The reason for the divengence in strain values during June is uncertain, although it may have been due to the softening or partial melting of the underlying ice sheet during this period.

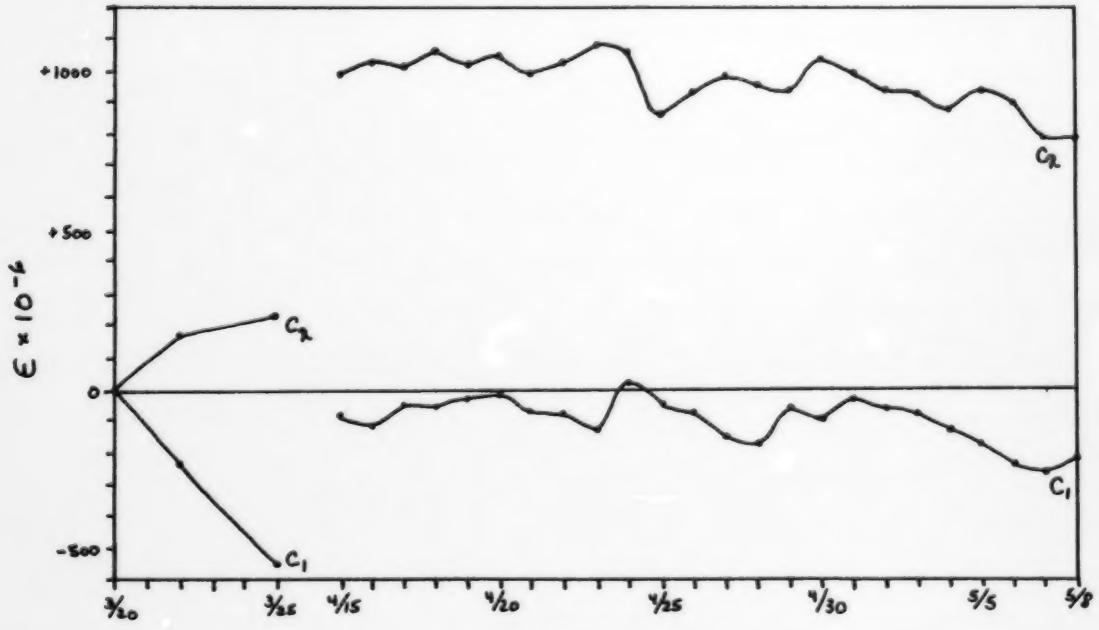

Figure 4 continued...

Because of the uncertain utility of strain values obtained prior to April 15, 1983, strain analyses were conducted in the following manner: Incremental strain values were calculated for the entire measurement period; finite strain was calculated twice, using March 20 and April 15 strain data as E_o values in the max/min strain calculations. These analyses are given below.

3.2 Finite Strain Values

As might be expected from the raw strainmeter values, there is not a strong correlation between the strainmeter values obtained over the period March 20 - April 15, 1983 (Table 3). From March 20-25, Rosette I recorded strains on the order of +1000 microstrains, yeilding a strain rate of $+2.4 \times 10^{-9}$ sec^{-1}. During the same period, Rosette II recorded values around +170 microstrains, giving a strain rate of approximately $4 \times 10^{-10} sec^{-1}$. This descrepancy is probably the result of equilibration between the strainmeter and the underlying ice sheet.

If we set E_o to be the state of ice strain on April 15, the strain values become more consistent between strainmeters. This is shown graphically in Figures 5 through 8, which compare E_{max}, E_{min}, $\emptyset$, Deviatoric E and Dilational E for the two rosettes. These figures (and Table 3) show that both rosettes exhibit similar trends through April, but differ in May, when E_{max} of rosette I decreases below that of rosette II. In general, however, strains are very low throughout this period, with a maximum strain value on the order of ±500 microstrains. This gives a strain rate around 1×10^{-10} sec^{-1}, which is much lower

than that recorded in March. Similarly. the surface area of the ice sheet tended to increase in March (Table 3) while a general contraction of the ice sheet was observed in April (Fig. 8). In both cases, however, the change in area was small and averaged -0.3% during the April occupation.

The orientation of E_{max} between March 20-May 8 tended towards an average value of -50 degrees, or approximately S78^{O}E (Fig. 6.). Variations in orientation during the initial part of April were probably due to the low finite strains recorded during this period.

As with the raw strainmeter values, the strain data analysed for June is widely divergent from that recorded in May. The analysed values are given in Table 3.

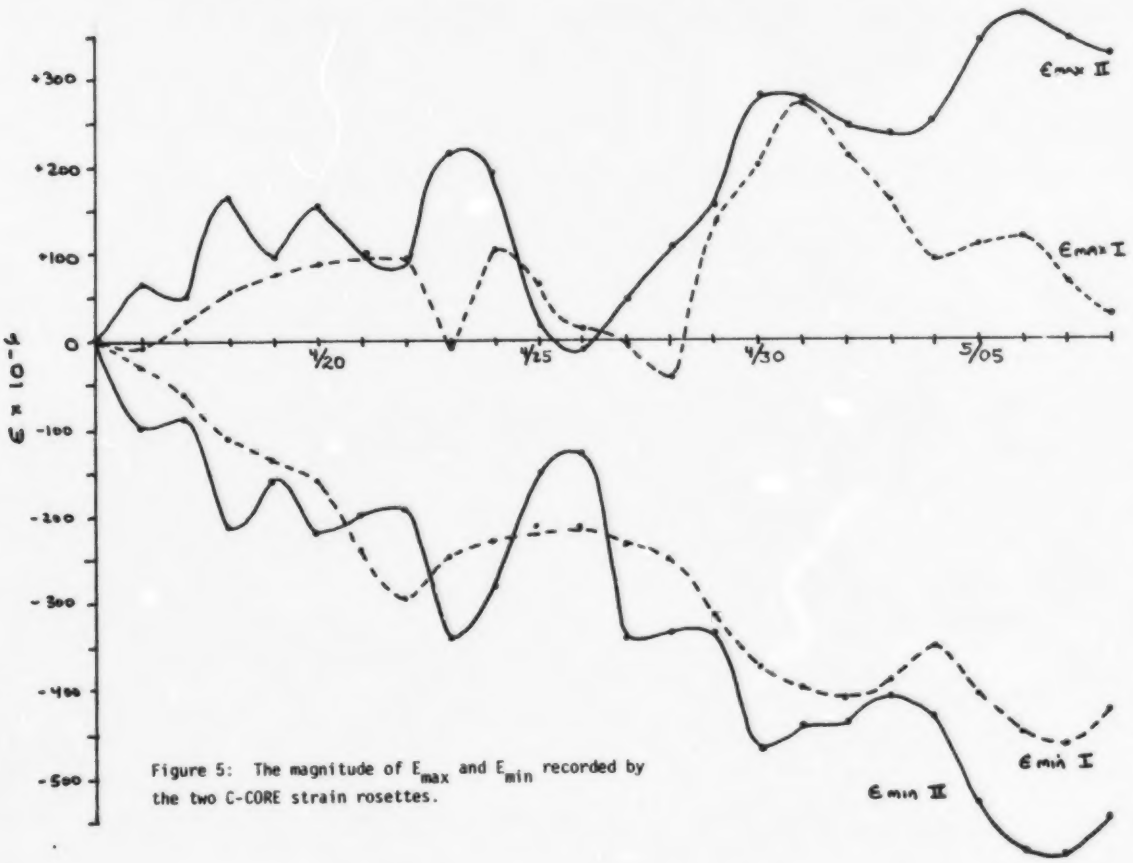

Figure 5: The magnitude of E_{max} and E_{min} recorded by the two C-CORE strain rosettes.

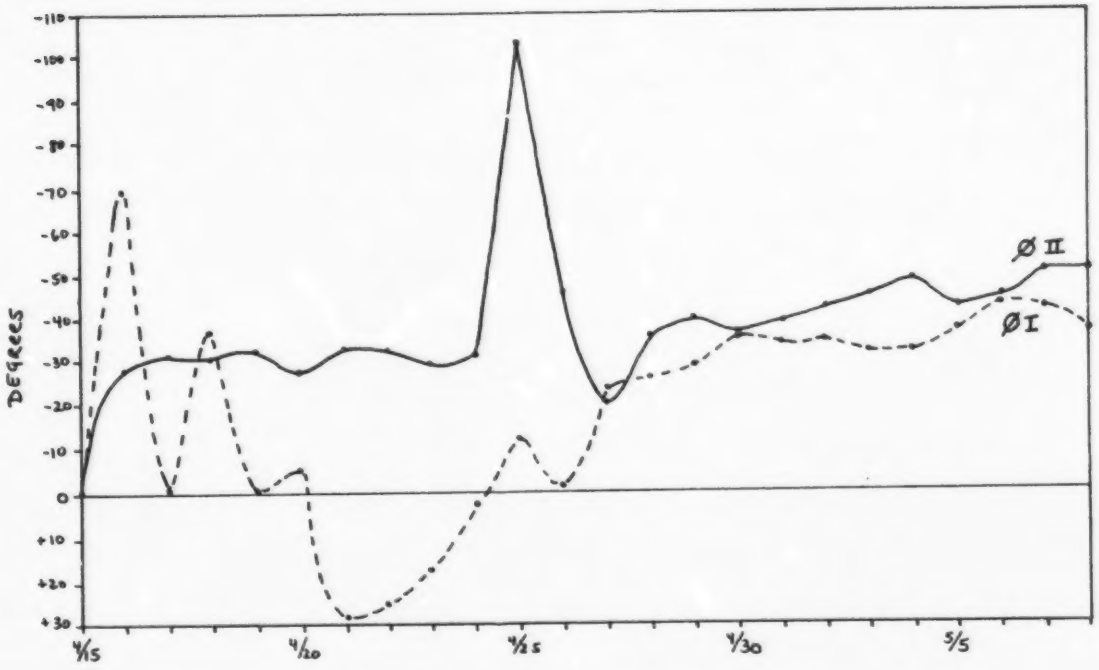

Figure 6: The orientation of E_{max} with respect to leg c of the two strain rosettes.

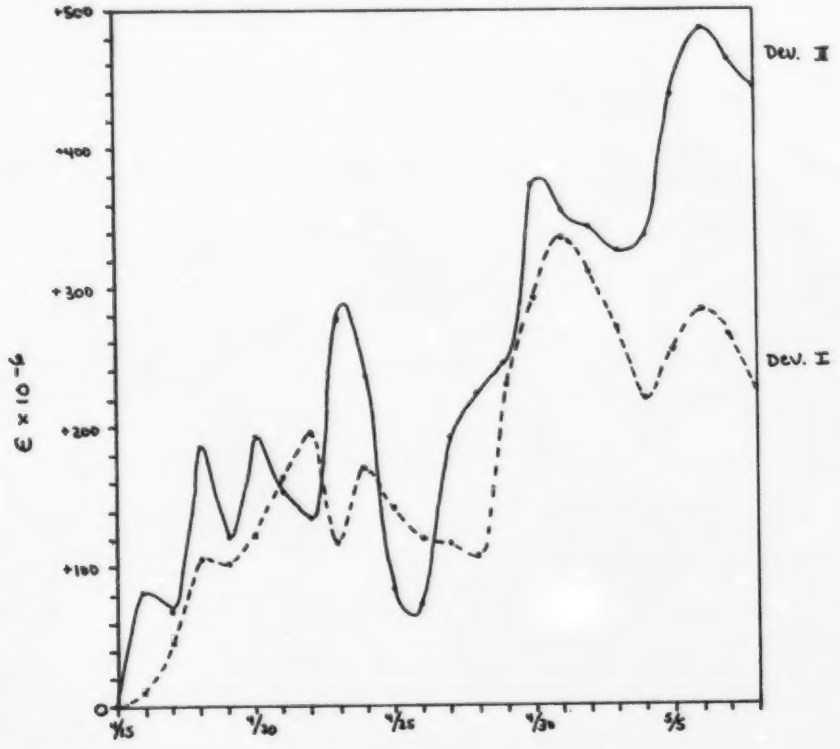

Figure 7: Deviatoric strains measured by the C-CORE strain rosettes.

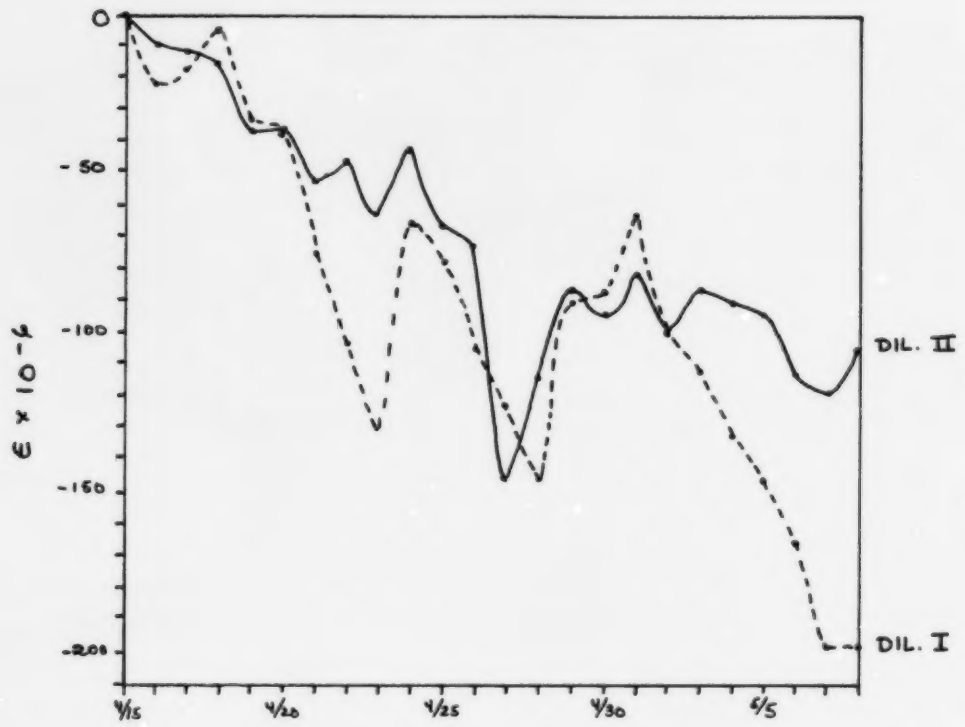

Figure 8: Dilational strains measured by the two C-CORE strain rosettes.

3.3 Incremental Strain Values

As with the finite strain values, incremental strain values were low. The average strain rate was approximately 9×10^{-10} sec $^{-1}$, and the highest recorded strain in a 24 hour period was 336 microstrains, measured on April 25, 1983. A value of 833 microstrains was noted on June 10, 1983, but this is an unsupported value and requires further confirmation. On the average, however, strain values remained less than 150×10^{-6} throughout the study period (Table 5 and Figures 9 and 10). The orientation of E_{max} was variable and does not seem to have been comparable between rosettes.

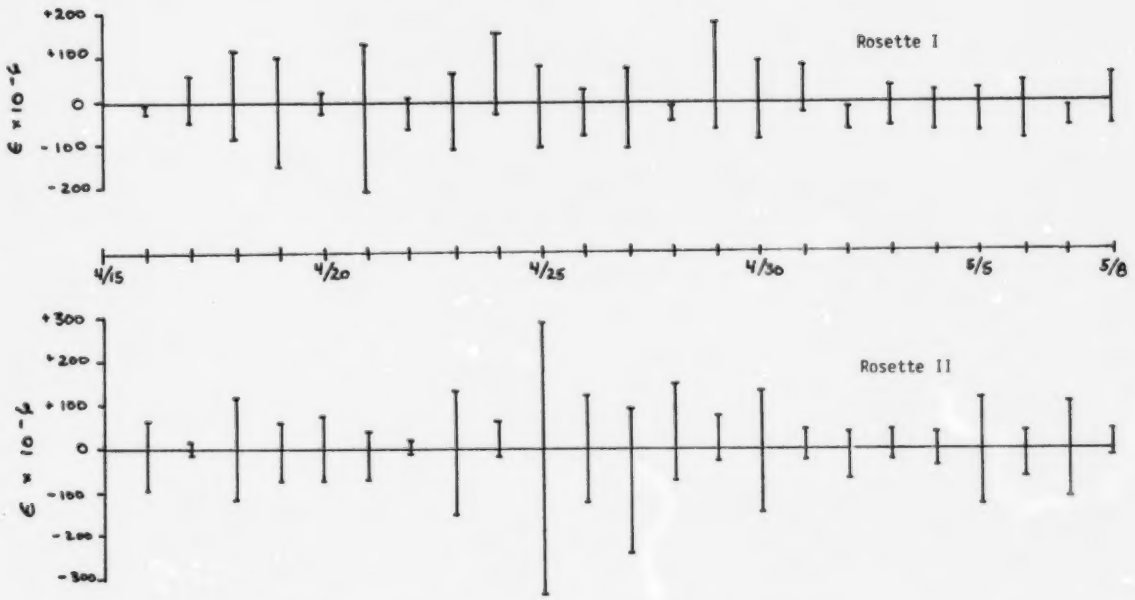

Figure 9: The magnitude of incremental strain measured by the two strain rosettes.

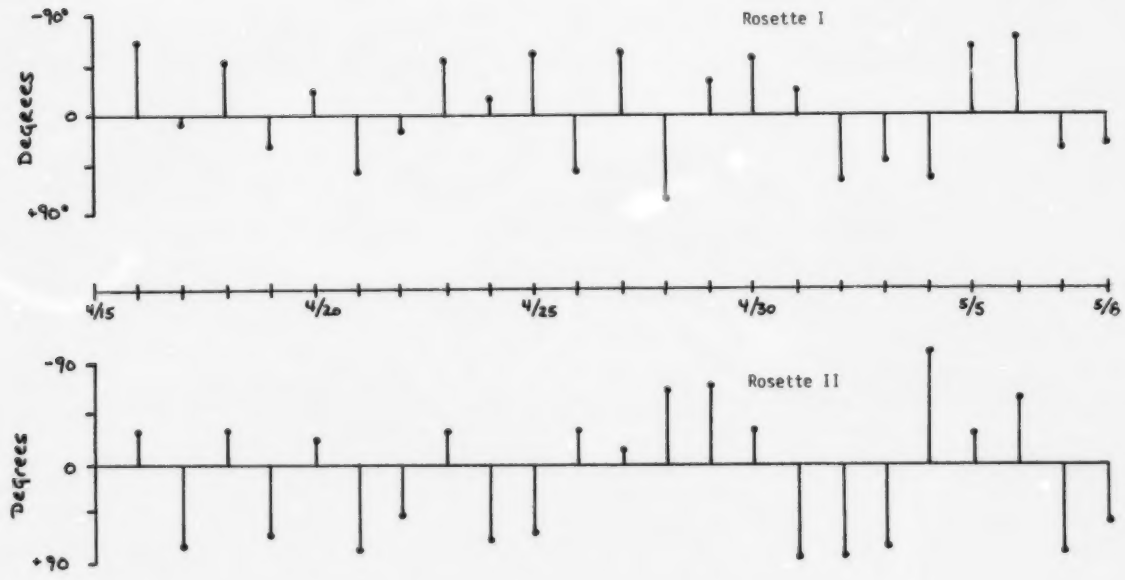

Figure 10: The orientation of incremental strain with respect to leg c of the two strain rosettes.

Deviatoric strains were very low. averaging 63×10^{-6} in the case of rosette I and 85×10^{-6} for rosette II. Dilational strains were generally negative and averaged less than 40×10^{-6} during a 24 hour period. These values do not seem to relate to changes in temperature as measured by the thermistor buried within the strainmeter body.

3.4 Comparison with EDM Strain Triangles

As mentioned earlier, 47 strain triangles were measured by N.R.C. during the period March 20 - June 14. 1983. Of these. one triangle surrounded the C-CORE strainmeter facility, and could therefore be compared to the smaller rosettes (Table 6). This strain triangle gave $E_{max} = 1550 \times 10^{-6}$, $E_{min} = -1770 \times 10^{-6}$ and $\emptyset = 33^{\circ}$ (N57°E) during the period March 20 - April 27. 1983. During this same period, the C-CORE rosettes recorded similar strain values ($E_{max} = 1228 \times 10^{-6}$, $E_{min} = -1740 \times 10^{-6}$), but the orientation of finite strain differed by approximately 60°. This variation may be due to the precision of the EDM. which is reported to have a resolution of $\pm$ 3 mm (160 microstrains) when used in the manner described above. It is unlikely that the difference in orientation is due to fracture development in the ice sheet. since this would lead to an increase in dilatency. a feature which was not noted during this analysis.

Forty-six other strain triangles were also analysed during this study and provide an overall record of finite strain for the ice surrounding Adams Island (Table 6). Of these. 22 exhibit low

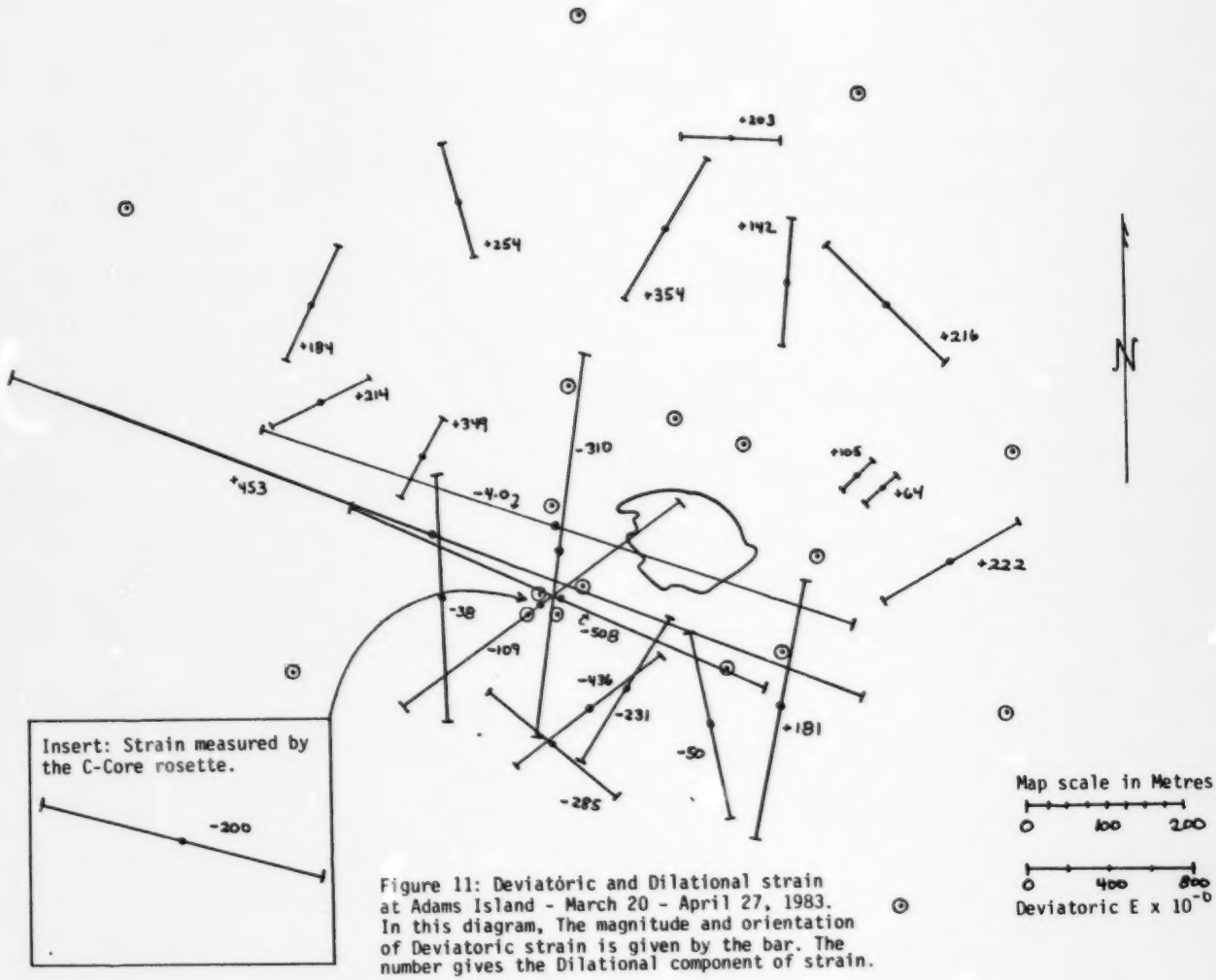

Figure 11: Deviatoric and Dilational strain at Adams Island - March 20 - April 27, 1983. In this diagram, The magnitude and orientation of Deviatoric strain is given by the bar. The number gives the Dilational component of strain.

dilatency values, suggesting little or no crack development during the study period. These orientations are presented graphically in Figure 11. It is interesting to note tha the strain triangle located adjacent to the C-CORE installation displayed nearly the same orientation and magnitude of strain as the smaller rossettes (see insert on Figure 11).

4. CONCLUSIONS

Strain measurements were made in the vicinity of Adams Island during the period March 20 - June 10, 1983. These measurements showed that small scale deformation in the ice sheet was minor during most of this period, and only increased in June. Values for the March and April measurement period were consistant between the two C-CORE strainmeters, suggesting that these values are realistic. In general, strain during the March - May period was less than ± 2000 microstrains, giving an average strainrate of less than 6×10^{-10} sec^{-1}. Softening of the ice sheet in June may have produced the high strain values noted during this period.

The magnitude of finite strain measured in the surrounding EDM triangle was consistant with that measured in the smaller rosettes. However, the orientation of strain differed by around 60^{o}. The cause of this discrepancy is presently unknown, but may be due to local perturbations in the strain field as suggested by the parallism of strain between the C-CORE rosettes and nearby strain triangles.

APPENDIX - TABLES

Table 1. Calibration constants and gage length in mm for strainmeter rosettes I and II.

Strainmeter Leg	Gage Length	Calibration constant (in mv/v/mm)
I-a	150 mm	55.00
I-b	150 mm	56.00
I-c	150 mm	55.80
II-a	140 mm	77.99
II-b	140 mm	78.01
II-c	140 mm	73.60

Table 2. Calculated strain values for each strainmeter leg.

DATE	Accumulated time (hrs.)	E x 10^{-6} c_1	a_1	b_1	c_2	a_2	b_2
3/20	ø	ø	ø	ø	ø	ø	ø
3/20	3.8	37.798	75.976	77.334	37.903	187.999	211.541
3/22	48.5	-230.005	-288.000	640.313	189.084	-5.950	+62.332
3/22	55.3	-218.363	-237.906	662.49	214.893	+116.548	0.567
3/25	121.0	-542.282	-529.586	1026.506	221.558	-22.770	240.868
4/15	624.7	-94.618	-1355.819	1050.638	992.674	-1346.626	1249.635
4/16	647.5	-121.979	-1379.396	1038.266	1016.117	-1447.309	1266.617
4/17	673.3	-66.423	-1399.515	1014.651	1001.803	-1435.884	1266.517
4/18	696.3	-69.973	-1465.902	1121.142	1059.028	-1556.490	1317.053
4/19	720.7	-23.920	-1444.638	970.576	1007.545	-1503.621	1280.092
4/20	743.9	-12.402	-1472.113	972.451	1064.250	-1575.666	1296.748
4/21	768.1	-86.395	-1349.674	810.339	998.788	-1546.149	1285.078
4/22	792.4	-82.330	-1382.790	754.929	1004.734	-1530.519	1281.726
4/23	817.1	-131.156	-1469.698	810.082	1070.891	-1683.976	1322.845
4/24	841.0	+6.703	-1486.698	880.125	1059.654	-1627.253	1335.145
4/25	863.1	-43.942	-1552.127	958.780	857.089	-1341.582	1177.183
4/26	891.8	-80.117	-1528.069	891.873	918.395	-1466.144	1226.462
4/27	912.3	-141.959	-1594.855	969.277	989.366	-1678.585	1140.876
4/28	936.2	-178.953	-1607.294	946.363	951.699	-1680.819	1281.101
4/29	962.0	-69.997	-1671.139	1071.125	939.638	-1660.144	1352.141
4/30	983.9	-99.708	-1727.995	1160.922	1013.565	-1805.997	1406.092
5/1	1009.5	-36.471	-1750.361	1199.151	992.945	-1771.541	1430.610
5/2	1031.9	-89.115	-1762.381	1150.658	992.487	-1757.176	1432.703
5/3	1055.9	-92.648	-1736.373	1094.698	905.108	-1715.067	1445.689
5/4	1079.3	-134.785	-1707.489	1047.232	866.795	-1711.454	1470.299
5/5	1104.2	-173.700	-1752.059	1082.331	935.851	-1839.263	1515.286
5/6	1127.7	-244.061	-1774.220	1121.251	894.059	-1883.234	1548.459
5/7	1152.7	-267.019	-1796.829	1067.681	783.048	-1811.835	1571.200
5/8	1178.0	-231.438	-1772.398	1011.379	784.275	-1774.191	1569.024
6/9	1728.0	-1867.541	-4435.049	2110.800	10,316.416	+9937.563	+2494.519
6/10	—	-1867.541	-4447.158	2669.765	10,200.072	+9233.049	3114.168

Table 3a. Calculated finite strain values for rosette I. ϕ is given with respect to leg C.

DATE	E x 10^{-6} Max	Min	ϕ	Dev x 10^{-6}	Dil x 10^{-6}	% Δ Area x 10^{-4}	$\dot{E}$ x 10^{-10} Max	Min
3/20	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ
3/20	89.61	37.78	-89.13	25.91	63.70	127.40	65.51	27.62
3/22	641.24	-559.70	-58.40	600.47	40.76	81.53	36.73	-32.06
3/22	662.59	-525.11	-59.46	593.85	+68.74	137.48	33.28	-26.38
3/25	1026.53	-1056.77	-60.20	1041.65	-15.12	-30.24	23.57	-24.26
4/15	1653.60	-112.37	+84.24	882.98	+770.61	1541.22	7.35	-0.49
4/16	1241.84	-1150.58	-44.34	1396.21	-154.37	-308.73	5.32	-6.65
4/17	1245.92	-1546.77	-43.27	1396.34	-150.42	-300.85	5.14	-6.38
4/18	1356.94	-1633.43	-43.69	1495.19	-138.24	-276.48	5.40	-6.51
4/19	1235.65	-1567.63	-42.09	1401.64	-165.99	-331.98	4.76	-6.03
4/20	1249.53	-1590.90	-41.80	1420.21	-170.68	-341.37	4.66	-5.93
4/21	1044.47	-1461.63	-42.20	1253.05	-208.57	-417.15	3.77	-5.28
4/22	1007.10	-1480.56	-41.43	1243.83	-236.73	-473.46	3.53	-5.18
4/23	1059.28	-1586.46	-42.13	1322.87	-263.59	-527.18	3.59	-5.39
4/24	1182.09	-1582.07	-40.70	1382.08	-199.98	-399.97	3.90	-5.22
4/25	1247.00	-1671.86	-41.68	1459.43	-212.43	-424.85	4.01	-5.37
4/26	1167.36	-1644.90	-41.76	1406.13	-238.77	-477.54	3.63	-5.12
4/27	1128.93	-1740.62	-42.80	1484.77	-255.84	-511.69	3.73	-5.29
4/28	1197.84	-1757.77	-43.04	1477.81	-279.96	-559.92	3.55	-5.21
4/29	1367.31	-1813.99	-42.23	1590.65	-223.33	-446.67	3.94	-5.23
4/30	1450.15	-1894.67	-42.90	1672.41	-222.26	-444.52	4.09	-5.35
5/1	1514.45	-1906.24	-42.33	1710.34	-195.89	-391.78	4.16	-5.25
5/2	1454.42	-1921.65	-42.55	1688.04	-233.61	-467.22	3.91	-5.17
5/3	1396.80	-1886.35	-42.34	1641.58	-244.77	-489.54	3.68	-4.96
5/4	1330.74	-1860.77	-42.66	1595.76	-265.01	-530.02	3.43	-4.79
5/5	1358.81	-1921.10	-43.12	1639.95	-281.14	-562.28	3.42	-4.83
5/6	1373.59	-1971.61	-44.06	1672.60	-299.01	-598.02	3.38	-4.86
5/7	1323.04	-1987.16	-43.87	1655.10	-332.05	-664.11	3.18	-4.79
5/8	1279.46	-1941.10	-43.23	1610.28	-330.81	-661.63	3.02	-4.58
6/9	2411.13	-5205.65	-48.54	3808.39	-1397.26	-2794.52	3.88	-8.36
6/10	2945.47	-5375.43	-49.51	4160.45	-1214.97	-2429.95	4.67	-8.52

Table 3b. Calculated finite strain values for rosette II.

DATE	$E \times 10^{-6}$ Max	Min	γ	Dev $\times 10^{-6}$	Dil $\times 10^{-6}$	% Δ Area $\times 10^{-4}$	$\dot{E} \times 10^{-10}$ Max	Min
3/20	ø	ø	ø	ø	ø	ø	ø	ø
3/20	254.46	37.03	-86.38	108.71	+145.74	291.49	186.0	27.07
3/22	196.09	-32.45	-10.09	114.27	+81.82	163.64	11.23	-1.86
3/22	234.55	-13.21	+16.36	123.88	+110.66	+221.33	11.78	-0.66
3/25	316.24	-23.13	-31.88	169.68	+146.55	+293.10	7.26	-0.53
4/15	1950.42	-1353.30	-32.58	1651.86	+298.56	+597.12	8.67	-6.02
4/16	2010.30	-1453.35	-32.39	1731.83	+278.47	+556.95	8.62	-6.24
4/17	1997.64	-1442.68	-32.54	1720.16	+277.47	+554.95	8.24	-5.95
4/18	2108.93	-1562.54	-32.32	1835.74	+273.19		8.41	-6.23
4/19	2033.29	-1510.62	-32.54	1771.96	+261.33	+522.67	7.84	-5.82
4/20	2104.11	-1580.56	-32.09	1842.34	+261.77	+523.55	7.86	-5.90
4/21	2045.56	-1553.75	-32.64	1799.66	+245.90	+491.81	7.39	-5.62
4/22	2041.63	-1537.67	-32.56	1789.65			7.16	-5.39
4/23	2162.65	-1689.47	-32.17	1926.06	+236.58	+473.17	7.35	-5.74
4/24	2145.65	-1633.95	-32.41	1889.80	+255.84	+511.69	7.09	-5.39
4/25	1814.19	-1352.40	-33.35	1583.30	+230.89	+461.79	5.84	-4.35
4/26	1927.94	-1475.46	-33.00	1701.70	+226.23	+452.47	6.00	-4.60
4/27	1981.78	-1680.67	-31.36	1831.22	-150.55	+301.10	6.03	-5.12
4/28	2058.47	-1690.49	-32.91	1874.48	+183.99	+367.98	6.11	-5.02
4/29	2096.33	-1675.24	-33.63	1885.78	+210.54	+421.09	6.05	-4.84
4/30	2227.83	-1818.72	-33.22	2023.28	+204.55	+409.10	6.29	-5.14
5/1	2222.20	-1787.52	-33.62	2004.86	+217.33	+434.67	6.11	-4.92
5/2	2177.90	-1779.22	-34.20	1978.56	+199.33	+398.67	5.86	-4.79
5/3	2163.99	-1740.17	-34.60	1952.08	+211.91	+423.82	5.69	-4.57
5/4	2159.90	-1742.81	-35.14	1951.36	+208.54	+417.09	5.56	-4.49
5/5	2274.38	-1866.46	-34.64	2070.42	+203.95	+407.91	5.72	-4.69
5/6	2290.29	-1917.43	-35.17	2103.86	+186.42	+372.85	5.64	-4.72
5/7	2224.74	-1863.13	-36.43	2043.93	+180.80	+361.60	5.36	-4.49
5/8	2211.76	-1825.69	-36.48	2018.72	+193.03	+386.07	5.22	-4.31
6/9	12,675.84	2489.82	+28.76	5093.01	+7582.83	15165.66	20.38	4.00
6/10	11,952.62	3078.90	+26.38	4436.86	+7515.76	15031.52	18.95	4.88

Table 4a. Calculated finite strain values for the April occupation, Rosette I.

DATE	$E \times 10^{-6}$ Max	$E \times 10^{-6}$ Min	ϕ	Dev $\times 10^{-6}$	Dil $\times 10^{-6}$	$\%\Delta$ Area $\times 10^{-4}$	$\overset{\circ}{E} \times 10^{-10}$ Max	$\overset{\circ}{E} \times 10^{-10}$ Min
4/15	0	0	0	0	0	0	0	0
4/16	-12.10	-30.10	-67.02	9.00	-21.10	-42.20	+1.47	-3.67
4/17	+28.41	-62.73	-2.80	45.57	-17.16	-34.32	+1.62	-3.58
4/18	+103.41	-113.36	-37.07	108.38	-4.97	-9.95	+4.01	-4.40
4/19	+70.82	-136.27	-1.39	103.54	-32.72	-65.45	+2.05	-3.94
4/20	+84.22	-159.06	-5.21	121.64	-37.42	-74.84	+1.96	-3.70
4/21	+89.68	-240.30	+29.79	164.99	-75.31	-150.62	+1.73	-4.66
4/22	+90.11	-297.04	+26.63	193.57	-103.46	-206.92	+1.49	-4.92
4/23	-11.39	-249.25	+18.97	118.93	-130.32	-260.49	-0.16	-3.60
4/24	102.86	-236.30	+3.86	169.58	-66.72	-133.44	+1.32	-3.03
4/25	63.99	-222.32	-12.45	143.16	-79.16	-158.32	+0.75	-2.59
4/26	14.75	-225.76	-1.85	120.25	-105.50	-211.00	+0.15	-2.34
4/27	-4.47	-240.68	-25.21	118.10	-122.57	-245.15	-0.01	-0.74
4/28	-41.28	-252.10	-26.86	105.41	-146.69	-293.39	-0.12	-0.75
4/29	+135.19	-315.33	-29.69	225.26	-90.07	-180.14	-0.39	-0.91
4/30	201.91	-379.90	-36.61	290.91	-88.99	-177.98	-0.57	-1.07
5/1	273.36	-398.61	-34.46	335.99	-62.62	-125.25	-0.75	-1.09
5/2	210.69	-411.38	-35.05	311.04	-100.34	-200.69	0.57	-1.11
5/3	158.63	-381.64	-32.58	270.14	-111.50	-223.01	0.42	-1.00
5/4	89.19	-352.69	-32.75	220.94	-131.74	-263.49	0.23	-0.91
5/5	108.59	-404.34	-37.22	256.46	-147.87	-295.75	0.27	-1.02
5/6	117.05	-448.54	-43.34	282.80	-165.74	-331.48	0.29	-1.11
5/7	66.98	-464.56	-42.15	265.77	-198.78	-397.57	0.16	-1.12
5/8	28.60	-423.70	-37.21	226.15	-197.55	-395.10	0.07	-0.99

Table 4b. Calculated strain values for the April occupation. Rosette II.

DATE	$E \times 10^{-6}$ Max	Min	∅	Dev $\times 10^{-6}$	Dil $\times 10^{-6}$	% Δ AREA $\times 10^{-4}$	$\overset{\circ}{E} \times 10^{-10}$ Max	Min
4/15	∅	∅	∅	∅	∅	∅	∅	∅
4/16	60.59	-100.76	-28.67	80.68	-20.08	-40.17	7.38	-12.28
4/17	47.24	-89.40	-31.87	68.32	-21.08	-42.16	2.70	-5.11
4/18	159.13	-209.86	-30.09	184.50	-25.36	-50.72	6.17	-8.14
4/19	82.88	-157.33	-32.14	120.11	-37.22	-74.44	2.40	-4.55
4/20	155.99	-229.55	-27.89	192.77	-36.78	-73.56	3.63	-5.35
4/21	95.18	-200.49	-33.28	147.84	-52.65	-105.31	1.84	-3.88
4/22	91.22	-184.37	-32.40	137.79	-46.58	-93.15	1.51	-3.05
4/23	213.41	-337.36	-29.69	275.39	-61.97	-123.94	3.08	-4.87
4/24	195.44	-280.86	-31.28	238.15	-42.71	-85.42	2.51	-3.61
4/25	13.66	-148.99	+73.31	81.33	-67.66	-135.32	0.16	-1.73
4/26	-16.66	-127.98	-46.00	55.65	-72.32	-144.64	-0.17	-1.33
4/27	47.75	-341.77	-20.84	193.76	-148.00	-296.01	-0.44	-3.30
4/28	109.00	-338.14	-35.39	223.57	-114.56	-229.13	-0.97	-3.01
4/29	154.70	-330.74	-40.85	242.72	-88.01	-176.03	+1.27	-2.72
4/30	279.64	-467.66	-36.04	373.65	-94.00	-188.01	2.16	-3.62
5/1	277.95	-440.40	-38.44	359.17	-81.22	-162.44	2.01	-3.18
5/2	244.73	-443.17	-42.57	343.95	-99.22	-198.44	1.67	-3.02
5/3	239.26	-412.56	-45.08	325.91	-86.65	-173.30	1.54	-2.66
5/4	249.91	-429.94	-48.02	339.93	-90.01	-180.02	1.53	-2.63
5/5	344.82	-534.02	-42.53	439.42	-94.60	-189.20	1.99	-3.09
5/6	370.39	-594.65	-44.19	482.52	-112.13	-224.26	2.05	-3.28
5/7	345.68	-581.19	-50.71	463.44	-117.75	-235.51	1.82	-3.06
5/8	337.82	-548.87	-51.70	443.35	-105.52	-211.05	1.70	-2.76

Table 5a. Calculated incremental strain values for rosette I.

DATE	E x 10^{-6} Max	E x 10^{-6} Min	ϕ	Dev x 10^{-6}	Dil x 10^{-6}	% Δ Area x 10^{-4}	$\dot{E}$ x 10^{-10} Max	$\dot{E}$ x 10^{-10} Min
3/20	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ
3/20	89.61	37.78	-89.13	25.91	+63.70	+127.40	65.5	27.6
3/21	565.60	-611.47	-57.29	588.53	-22.93	-45.86	35.2	-38.0
3/22	50.91	+5.02	+67.68	22.94	+27.97	+55.94	20.8	+2.05
3/25	364.40	-532.12	-61.19	448.26	-83.86	-167.72	15.4	-22.5
4/15	1912.26	-340.79	+53.73	1126.53	+785.73	+1571.46	10.55	-1.87
4/16	-12.10	-30.10	-67.02	9.00	-21.10	-42.20	-1.47	-3.67
4/17	55.59	-47.71	+1.12	51.65	+3.94	+7.88	5.98	-5.14
4/18	113.22	-88.85	-49.48	101.04	+12.18	+24.36	13.11	-10.28
4/19	95.89	-151.39	+26.67	123.64	-27.75	-55.49	10.92	-17.24
4/20	18.75	-28.14	-23.13	23.45	-4.69	-9.38	2.25	-3.37
4/21	130.31	-206.09	+51.19	168.20	-37.88	-75.77	14.96	-23.66
4/22	6.54	-62.84	+10.88	34.69	-28.15	-56.30	0.75	-7.18
4/23	58.04	-111.77	-52.49	84.90	-26.86	-53.72	6.53	-12.57
4/24	153.29	-26.09	-17.05	89.69	+63.60	+127.20	17.82	-3.03
4/25	79.04	-103.93	-57.34	91.49	-12.44	-24.88	9.94	-13.06
4/26	27.09	-79.77	+50.30	53.43	-26.34	-52.68	2.62	-7.72
4/27	77.44	-111.59	-59.13	94.52	-17.07	-34.14	10.49	-15.12
4/28	-9.88	-38.34	+77.42	14.22	-24.11	-48.23	-1.15	-4.46
4/29	177.44	-64.19	-32.16	120.81	+56.62	+113.24	19.10	-6.91
4/30	91.17	-89.01	-54.99	90.09	+1.07	+2.15	11.56	-11.29
5/1	77.19	-24.46	-21.74	50.82	+26.36	+52.73	8.38	-2.65
5/2	-11.90	-63.53	+62.66	25.81	-37.71	-75.43	-1.48	-7.88
5/3	36.77	-59.09	+40.42	47.93	-11.16	-22.32	4.26	-6.84
5/4	28.98	-69.46	+58.20	49.22	-20.24	-40.47	3.44	-8.25
5/5	35.20	-67.46	-58.17	51.33	-16.12	-32.25	3.93	-7.53
5/6	45.27	-81.10	-73.05	63.23	-17.86	-35.73	5.36	-9.59
5/7	-12.52	-53.57	+30.28	20.52	-33.04	-66.09	-1.39	-5.95
5/8	59.13	-56.66	+26.81	57.89	+1.23	+2.47	6.49	-6.22
6/9	1179.04	-3311.93	-52.35	2245.49	-1066.44	-2132.88	5.95	-16.7
6/10	559.03	-194.45	-59.47	376.74	+182.28	+364.57	64.70	-22.51

Table 5b. Calculated incremental strain values for rosette II.

DATE	E x 10^{-6} Max	Min	ϕ	Dev x 10^{-6}	Dil x 10^{-6}	%Δ Area x 10^{-4}	$\dot{E}$ x 10^{-10} Max	Min
3/20	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ	ϕ
3/20	254.46	37.03	-86.38	108.71	145.74	291.49	186.0	27.07
3/22	152.71	-280.56	-3.40	216.63	-63.92	-127.85	9.49	-17.43
3/22	135.27	-77.58	+45.81	106.42	+28.84	+57.69	55.26	-31.69
3/25	256.99	-185.22	+48.79	221.11	+35.88	+71.76	10.87	-7.83
4/15	1634.23	-1330.22	-32.66	1482.22	+152.00	+304.01	9.01	-7.33
4/16	60.59	-100.76	-28.68	80.68	-20.08	-40.17	7.38	-12.28
4/17	13.89	-15.88	-76.72	14.88	-0.99	-1.99	1.49	-1.71
4/18	112.10	-120.67	-29.04	116.38	-4.28	-8.56	13.54	-14.57
4/19	53.41	-77.12	+63.69	65.26	-11.85	-23.71	6.08	-8.78
4/20	76.52	-75.64	-21.15	76.08	+0.43	+0.87	9.16	-9.06
4/21	39.12	-70.86	+77.19	54.99	-15.87	-31.74	4.49	-8.14
4/22	17.03	-4.88	+45.34	10.96	+6.07	+12.14	1.95	-.588
4/23	123.42	-154.21	-27.01	138.81	-15.39	-30.78	13.88	-17.34
4/24	59.11	-20.58	+69.96	39.85	+19.26	+38.52	6.87	-2.39
4/25	286.73	-336.64	+62.37	311.68	-24.95	-49.90	36.04	-42.31
4/26	115.44	-124.76	-28.34	120.10	-4.65	-9.31	11.17	-12.08
4/27	88.24	-239.61	-13.26	163.92	-75.68	-151.37	11.96	-32.47
4/28	142.16	-75.28	-65.42	108.72	+33.44	+66.83	16.52	-8.75
4/29	74.88	-21.78	-71.50	48.33	+26.55	+53.10	8.06	-2.35
4/30	134.34	-146.32	-27.64	140.33	-5.99	-11.98	17.04	-18.56
5/1	46.67	-21.10	+85.12	33.89	+12.78	+25.56	5.06	-2.29
5/2	34.93	-70.93	+86.15	52.93	-18.00	-36.00	4.33	-8.79
5/3	46.92	-21.77	+75.34	34.34	+12.57	+25.14	5.43	-2.52
5/4	33.62	-40.35	-80.43	36.99	-3.36	-6.72	3.99	-4.79
5/5	119.41	-128.59	-26.78	124.00	-4.58	-9.17	13.32	-14.35
5/6	33.18	-68.24	-59.28	50.71	-17.53	-35.06	3.92	-8.07
5/7	103.44	-114.69	+82.53	109.06	-5.62	-11.24	11.49	-12.74
5/8	37.72	-13.25	+57.79	25.48	+12.23	+24.46	4.14	-1.46
6/9	13975.44	804.14	35.50	6585.64	+7389.59	+14779.59	70.58	4.06
6/10	699.02	-833.16	-46.84	766.09	-67.07	-134.13	80.91	-96.43

Table 6. Calculated strain values for the 47 EDM strain triangles. ∅ is calculated with respect to the first two EDM sites given in the left hand column. Thus, in the case of SM1, 2, 3, E_1= SM 2/3; E_2= SM 2/3; and E_3= SM 3/1.

Triangle	Total E x 10^{-6} Max	Min	∅	± Deviatoric E x 10^{-6}	Dilational E x 10^{-6}	% Area x 10^{-4}
SM1, 2, 3	1550.556	-1770.271	33.65	1660.414	-109.858	-219.715
I4, 2, 3	5252.343	-537.864	-25.89	2895.104	+2357.240	+4714.479
I6, 3, 5	-29.286	-1382.242	+8.426	676.478	-705.764	-1411.528
I7, 8, 6	5899.783	-758.169	+51.56	3328.976	+2570.807	+5141.614
I1, 3, S2	3006.118	-3014.862	-69.062	3010.490	-4.372	-8.744
I6, 4, 5	-70.298	-1524.679	+3.097	727.191	-797.489	-1594.977
I5, 2, 4	5060.513	-641.632	-49.2827	2851.073	+2209.441	+4418.881
I4, 1, 2	4270.272	+915.947	+15.793	1677.163	+2593.110	+5186.219
I1, S3, I2	1565.930	-2187.388	+73.488	1876.659	-310.729	-621.458
I7, S1, S3	1664.367	-2680.964	-83.388	2172.666	-508.299	-1016.597
I7, 5, 6	7461.597	-289.277	31.216	3875.437	+3586.160	+7172.320
I7, S1, I1	685.827	-3464.151	9.653	2074.989	-1389.162	-2778.324
06, I6, 05	981.509	-535.909	+68.23	758.709	+222.800	+445.600
06, I7, 05	2175.22	-482.918	-59.06	1329.069	+846.151	+1692.302
06, I7, I6	6108.782	-403.845	-71.974	3256.314	+2852.469	+5704.937
05, I6, I5	279.817	-150.355	+13.782	215.076	+64.741	+129.482
05, I6, I4	285.907	-74.584	+16.911	180.246	+105.662	+211.323
05, I7, I5	2670.329	-151.688	-25.019	1411.009	+1259.321	+2518.641
05, I7, I6	6702.693	-2727.565	-43.918	4715.129	+1987.564	+3975.128
06, I5, 05	1326.587	-193.779	+78.762	760.183	+566.404	+1132.808
07, I8, 06	2935.204	-829.341	+80.690	1882.273	+1052.932	+2105.863
07, I6, 06	2651.183	-350.348	+42.649	1500.766	+1150.932	+2300.835
07, I8, I6	5157.767	-1015.634	+77.968	3086.701	+2071.067	+4142.133
07, 08, I8	-729.646	-1138.710	+33.318	204.532	-934.178	-1868.356
08, S2, I8	444.367	-1318.137	-59.609	881.252	-436.885	-873.770
07, S2, I8	867.508	-867.922	-36.716	917.715	-50.207	-100.414
07, 08, 06	2776.019	-1322.137	-74.12	2049.078	+726.941	+1453.882
07, 08, I6	1468.873	-1105.512	+79.211	1287.193	+181.681	+363.361
I8, S1, I1	596.966	-2970.184	-10.099	1783.575	-1186.609	-2373.218
05, I5, 04	1028.763	-594.948	-44.142	811.856	+216.908	+433.815
I5, I4, 04	755.538	-471.228	-74.428	613.383	+142.155	+284.310
I5, 03, 04	667.960	-261.482	+44.788	464.721	+203.239	+406.478
06, 08, I8	678.210	-2426.374	-18.345	1552.292	-874.082	-1748.164
07, 08, S2	-229.528	-1588.642	+40.503	679.557	-909.085	-1818.170
08, I2, I8	622.173	-1084.574	-36.538	853.374	-231.201	-462.401
08, 01, S2	524.124	-1786.087	+.9310	1155.106	-630.982	-1261.963
08, 01, I8	523.623	-1094.401	+.4708	809.012	-285.389	-570.778
I8, 01, S2	599.047	-2761.136	+61.063	1680.092	-1081.045	-2162.089
S2, 01, I2	1154.076	-1231.981	+79.06	1193.029	-38.953	-77.905
I2, 01, I3	4912.926	-4005.901	-55.974	4459.414	+453.513	+907.025
05, I5, I3	3352.235	-345.946	-66.518	1849.091	+1503.145	+3006.289
05, I5, I4	2940.161	-470.130	-62.824	1705.146	+1235.016	+2470.031
I3, 01, 02	748.109	-318.464	-20.977	533.287	+214.823	+429.645
03, 01, 02	785.804	-416.264	+1.057	601.034	+184.770	+369.540
03, 01, I3	794.827	-95.558	+5.90	445.193	+349.635	+699.269
I5, I4, 03	1137.498	-428.309	+80.186	782.904	+354.595	+709.189
03, I3, 02	830.737	-321.609	+17.402	576.173	+254.564	+509.128